Acoustic Reflection and Transmission Properties of Several Transducer Window Materials

G. R. Barnard, J. L. Bardin J. W. Whiteley

Defense Research Laboratory, The University of Texas

Austin, Texas

1978

17p.

INTRODUCTION

The transmission, reflection, and absorption characteristics of a material largely determine its usefulness in underwater sound applications. Uses may include transducer windows, sonar domes, sound reflectors, and linings for test tanks. Most of the experimental data available in the literature are for normal incidence of a plane wave on the material. However, in some applications it is desirable to know the acoustic properties of a material for angles of incidence other than normal. For these reasons a test system was devised to experimentally determine the acoustic properties of materials over a wide range of incident angles. Theoretically, the most straightforward approach to the case of arbitrary incidence is found in Brekhovskikh. The expressions for transmission and reflection coefficients will be used to compare theory and experiment. Hence it is the purpose of this paper to experimentally determine these coefficients for Absonic-A, Plexiglas, Soab, Polyethylene, and Fiberglass for frequencies ranging from 100-500 kc, compare the results with theory, and then examine their usefulness in underwater sound applications based upon these results.

107 500

THEORETICAL

Brekhovskikh's theory presents the case of transmitting infinite plane waves through an arbitrary number of solid layers. It makes allowance for arbitrary incident angles and reflections at boundaries. A brief rather than complete development of the theory will be presented here.

The coordinate system used in the development is shown in SLIDE 1. P_i is the incident wave, P_r the reflected wave, and P_t the transmitted wave. The potential functions of longitudinal and transverse waves in the nth solid layer resulting from a plane wave incident in medium n + 1 can be written as:

$$\Phi = (\Phi' e^{i\alpha z} + \Phi'' e^{-i\alpha z})\; e^{i(\sigma x - \omega t)}$$

$$\Psi = (\Psi' e^{i\beta z} + \Psi'' e^{-i\beta z})\; e^{i(\sigma x - \omega t)} \quad .$$

Here

$$\alpha = \sqrt{(k_n^2 - \sigma^2)} = k_n \cos \theta_n$$

(i.e., α is the z-component of the wave vector for the longitudinal wave),

$$\beta = \sqrt{(K_n^2 - \sigma^2}$$

(β represents the z-component of the wave vector for the shear wave), and

$$\sigma = k_n \sin \theta_n = k_{n+1} \sin \theta_{n+1} = K_n \sin \gamma_n$$

(σ represents the x-component of the wave vector for both waves). The magnitude of the incident longitudinal wave is Φ' and Φ'' is the magnitude of the reflected wave. The symbols Ψ' and Ψ'' represent similar magnitudes for the shear wave.

In order to express the pressure amplitude in one medium in terms of that in another, relationships must be obtained for the particle velocities and stress components in each medium. After these relationships have been obtained, the transmission and reflection coefficients are easily found. If it is assumed that medium n + 1 and 1 are liquids as in this experiment, the transmission and reflection coefficients are defined as:

$$V = \frac{\Phi''}{\Phi'} \quad \text{and} \quad T = \frac{\rho_1}{\rho_{n+1}} \frac{\Phi'''}{\Phi'} \quad .$$

The final expressions for these quantities are

$$T = \frac{2Nz_1}{M(z_1 + z_3) + i\left[(N^2 - M^2)\, z_1 + z_3\right]}$$

and

$$V = \frac{M(z_1 - z_3) + i\left[(N^2 - M^2)\, z_1 - z_3\right]}{M(z_1 + z_3) + i\left[(N^2 - M^2)\, z_1 + z_3\right]} \quad ,$$

where

$$M = \frac{z_2}{z_1} \cos^2 2\gamma_2 \cot P + \frac{z_{2t}}{z_1} \sin^2 2\gamma_2 \cot Q \quad ,$$

$$N = \frac{z_2}{z_1}\frac{\cos^2 2\gamma_2}{\sin P} + \frac{z_{2t}}{z_1}\frac{\sin^2 2\gamma_2}{\sin Q} \quad ,$$

$$z_i = \rho_i c_i/\cos\theta_i \rightarrow \text{acoustic impedance} \quad ,$$

$$P = -\alpha_2 D = -k_2 D \cos\theta_2 \quad \text{and} \quad Q = -\beta_2 D = -KD \cos\gamma_2 \quad .$$

Absorption is included in these expressions by making the wave number complex, i.e.,

$$k = k_{ph} + iA \quad ,$$

where

$$k_{ph} = \frac{\omega}{C_{ph}}$$

$$C_{ph} \rightarrow \text{phase velocity of propagation} \quad .$$

The longitudinal velocity may be written as

$$C = \frac{\omega}{k} = \frac{\omega}{\sqrt{k_{ph}^2 + A^2}}\, e^{-i\nu}$$

$$\nu = \tan^{-1}\frac{A}{k_{ph}} \quad .$$

Hence the acoustic impedance will be complex since

$$z_i = \rho_i c_i/\cos\theta_i \quad .$$

Snell's Law is used to relate the angles

$$k_{n+1} \sin \theta_{n+1} = k_n \sin \theta_n = K_n \sin \gamma_n \quad .$$

The preceding expressions were programmed for the Control Data 1604 Computer. The transmission and reflection coefficients were computed as the grazing angle (the angle a perpendicular with the wavefront makes with the interface) is varied from zero to 90° in 1/2° increments. The longitudinal and shear absorption was varied until the best agreement between theoretical and experimental curves was obtained.

EXPERIMENTAL

Slide 4

The measurements were made in a laboratory tank which measures 8 ft in diameter and 7 ft in depth. A pulsed technique was used to avoid multiple reflections in the tank. A mechanical positioning system afforded close control of the x, y, and z coordinates. The transducer positions were controlled to within 6 mils horizontally, 10 mils vertically, and .1° in tilt. The dynamic response of the system was 60 dB and a complete set of readings could be repeated within 1 dB. The area insonified by the half power beamwidths was an ellipse whose major axis rarely exceeded 1.5 ft. By choosing materials whose dimensions were at least twice this length, the portions of the wave not striking the material were quite small in amplitude. Care was taken to keep the hydrophone and material in the farfield of the projector. The expression D^2/λ was used to determine distance to the farfield where D is the diameter of the transducers and λ is the wavelength of the pressure wave.

COMPARISON OF EXPERIMENTAL AND THEORETICAL

Slides 5 and 6

Experimental measurements were made on Absonic-A, Plexiglas, Fiberglass, Polyethylene (low-density), and Soab. The comparison between theoretical and experimental values shown here is for 1/4 in. Absonic-A at 500 kc. The parameter values need some explanation. The value for velocity of sound in water was taken from a temperature-velocity curve for fresh water after the temperature was measured. The longitudinal velocity is measured, but the shear velocity is a book value. Varying the longitudinal and shear absorptions enabled one to obtain good agreement between experimental and theoretical curves. By varying other parameters slightly, even better agreement could be obtained. However, it was felt to be unnecessary since typical values were used throughout the calculations.

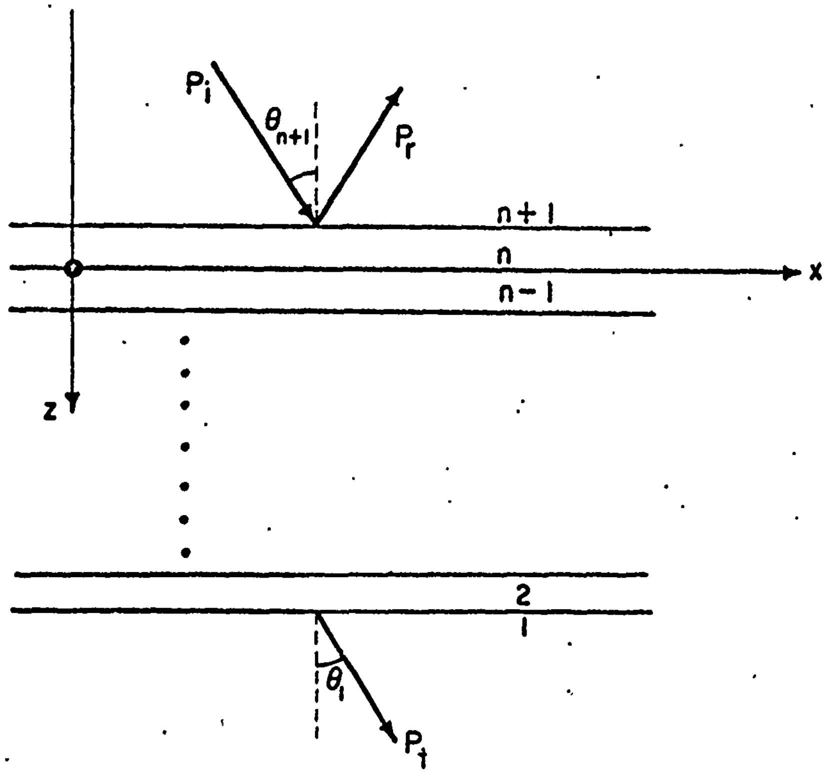
COMPARISON BETWEEN MATERIALS

For the materials used in this experiment, certain conclusions can be reached concerning their usefulness in underwater sound applications. Slide 7 is a comparison between Absonic-A and Plexiglas at 270 kc. Absonic-A has a slightly better transmission characteristic at normal incidence indicating it would be the better choice for a transducer window material. Its use as a sonar dome would be preferred also since it has acceptable transmission characteristics over a wider range of grazing angles.

Slide 8 indicates that Polyethylene (low-density) has transmission properties similar to Absonic-A. However, Absonic-A might be preferred in applications where structural rigidity is important. Slide 8 also illustrates why Soab is often used as a sound absorber. This is shown even more clearly on Slide 9. The absorptive loss in the Soab has increased greatly, indicating that the absorption is frequency dependent. Fiberglass is often used in sonar domes because of its structural advantages. Slide 10 indicates that it is acoustically acceptable over a certain range of incident angles.

CONCLUSIONS

Experimental verification of the theoretical expressions indicates that theory may be used to predict transmission and reflection coefficients quite accurately. By combining experimental data with theory, the absorption properties of each material can be predicted. Determination of these properties then allows one to judge its usefulness in underwater sound applications.



Slide 1

[redacted]

n-LAYERED MEDIA

DRL - UT
DWG AS 9109 987
JLB - BEE
3 - 17 - 64

$$\Phi = (\Phi' e^{i\alpha z} + \Phi'' e^{-i\alpha z})\, e^{i(\sigma x - \omega t)} \tag{1}$$

$$\Psi = (\Psi' e^{i\beta z} + \Psi'' e^{-i\beta z})\, e^{i(\sigma x - \omega t)} \tag{2}$$

$$\alpha = \sqrt{(k^2_n - \sigma^2)} = k_n \cos \theta_n \tag{3}$$

$$\beta = \sqrt{(K^2_n - \sigma^2)} = K_n \cos \gamma_n \tag{4}$$

$$\sigma = k_n \sin \theta_n = k_{n+1} \sin \theta_{n+1} = K_n \sin \gamma_n \tag{5}$$

$$V_x = \frac{\partial \Phi}{\partial x} - \frac{\partial \Psi}{\partial z} \tag{6}$$

$$V_y = 0 \tag{7}$$

$$V_z = \frac{\partial \Phi}{\partial z} + \frac{\partial \Psi}{\partial x} \tag{8}$$

$$S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \tag{9}$$

$$z_i = C_{ij}\, S_j \tag{10}$$

$$V = \frac{\Phi''}{\Phi'} \qquad T = \frac{\rho_1}{\rho_n}\frac{\Phi'''}{\Phi'} \tag{11}$$

$$T = \frac{2Nz_1}{M(z_1 + z_3) + i\left[(N^2 - M^2)\, z_1 + z_3\right]} \tag{12}$$

$$V = \frac{M(z_1 - z_3) + i\left[(N^2 - M^2)\, z_1 - z_3\right]}{M(z_1 + z_3) + i\left[(N^2 - M^2)\, z_1 + z_3\right]} \tag{13}$$

$$M = \frac{z_2}{z_1}\cos^2 2\gamma_2 \cot P + \frac{z_{2t}}{z_1}\sin^2 2\gamma_2 \cot Q \tag{14}$$

$$N = \frac{z_2}{z_1}\frac{\cos^2 2\gamma_2}{\sin P} + \frac{z_{2t}}{z_1}\frac{\sin^2 2\gamma_2}{\sin Q} \tag{15}$$

$$z_i = \rho_i c_i / \cos\theta_i \tag{16}$$

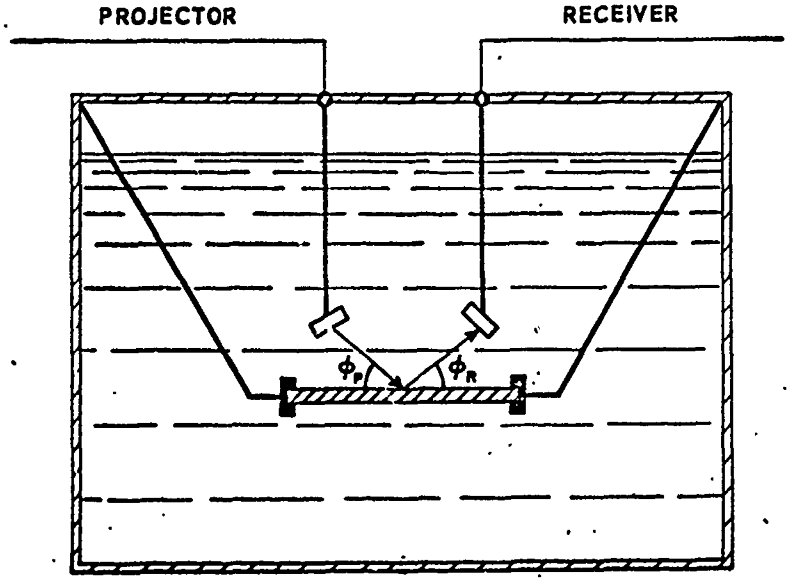
$$P = -\alpha_2 D = -k_2 \cos\theta_2 D \tag{17}$$

$$Q = -\beta_2 D = -K_2 \cos\gamma_2 D \tag{18}$$

$$k = k_{ph} + iA \tag{19}$$

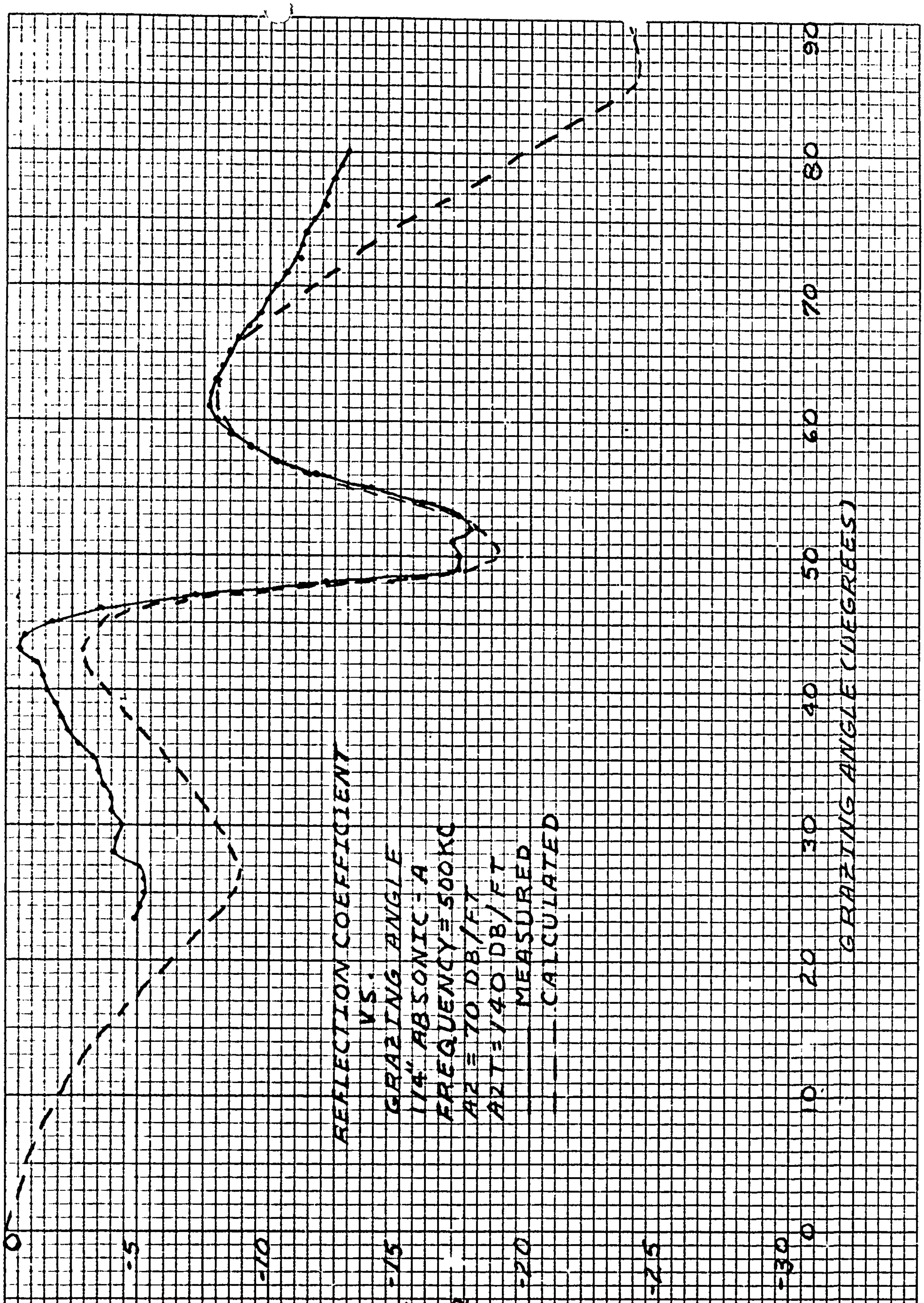
$$c = \frac{\omega}{k} = \frac{\omega}{\sqrt{k_{ph}^2 + A^2}}\, e^{-i\nu} \quad ; \quad \nu = \tan^{-1}\frac{A}{k_{ph}} \tag{20}$$

Slide 3

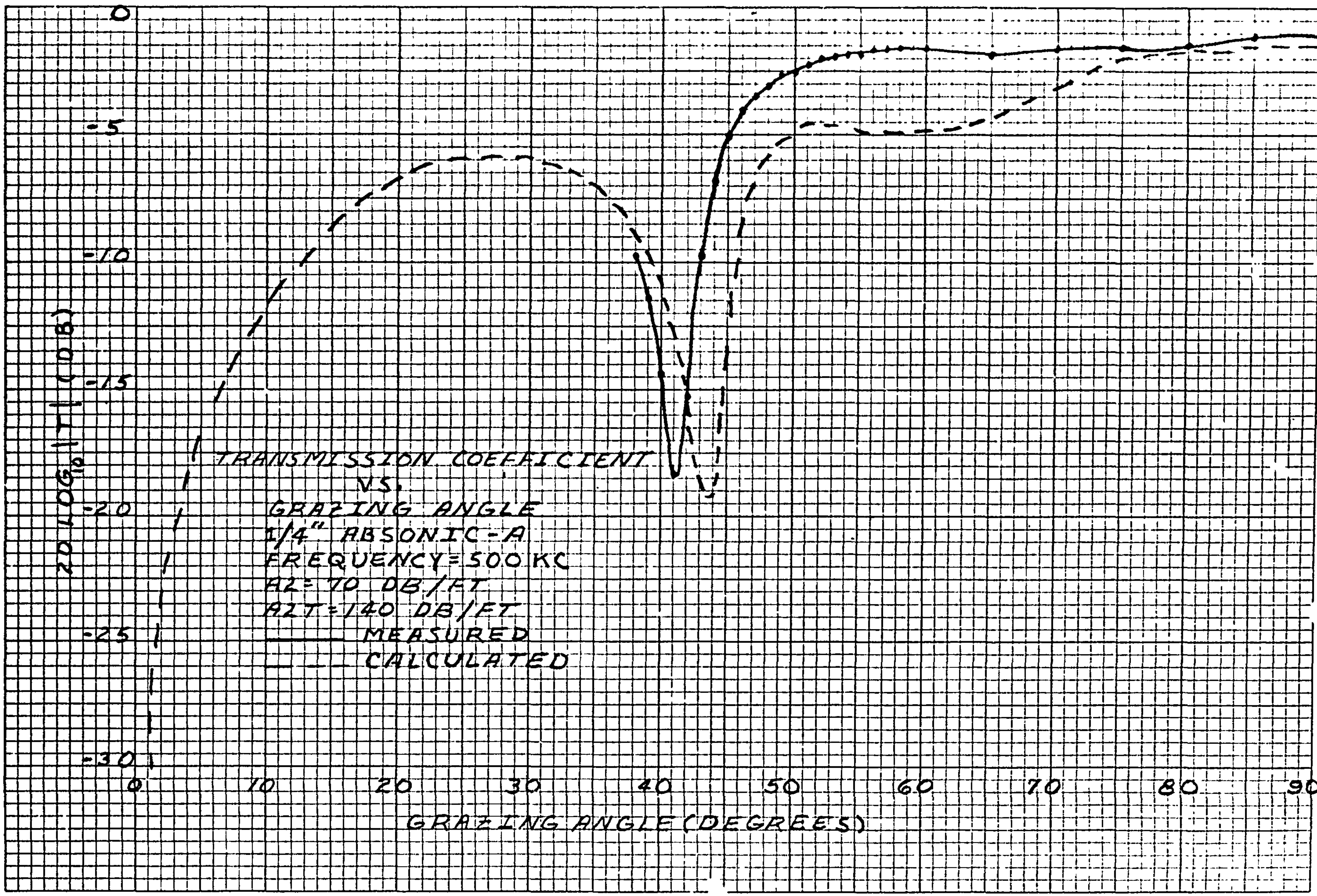


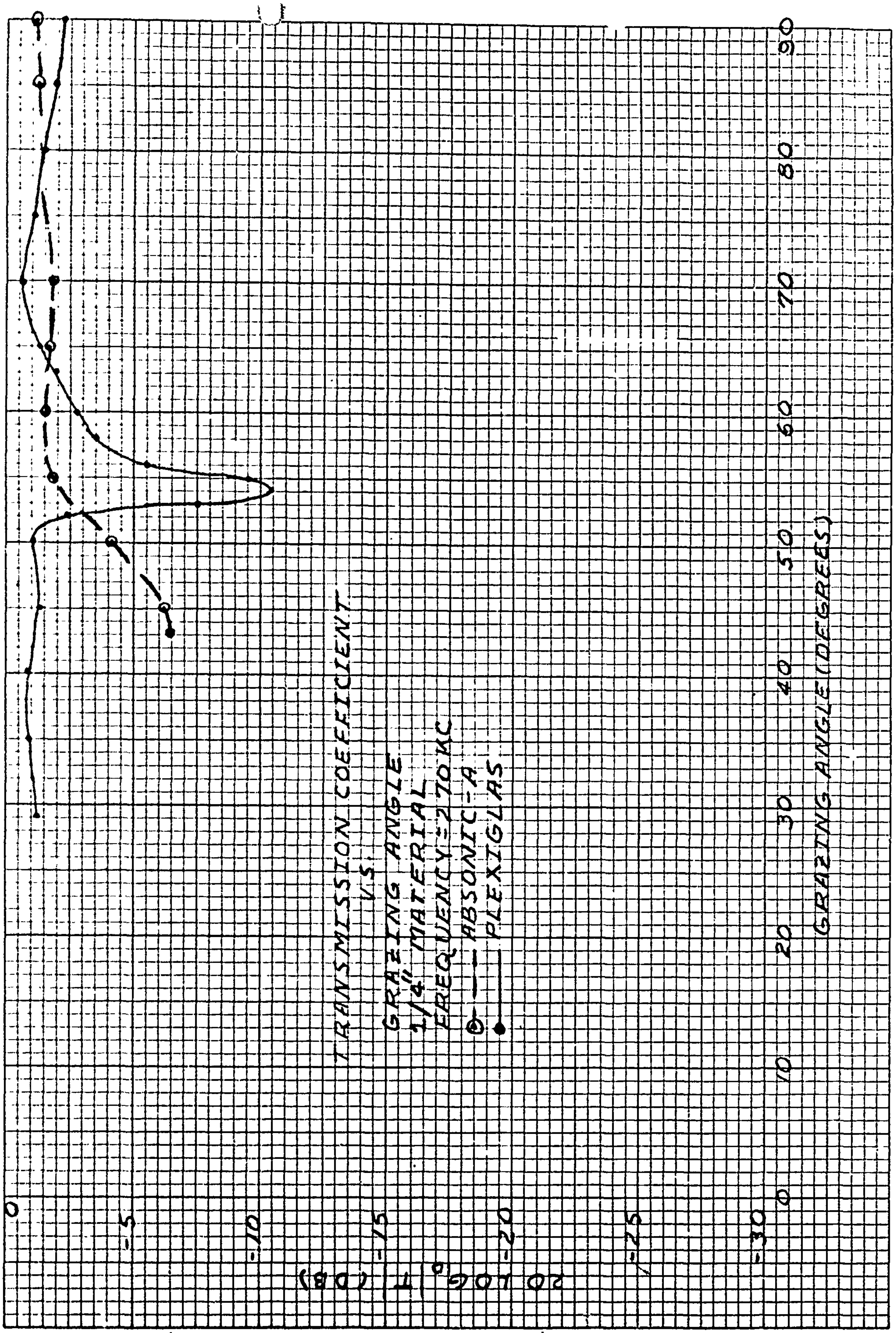
Slide 4
[redacted]
REFLECTION MEASUREMENTS

DRL - UT
DWG AS-~~8062~~ 9E3(
JLB - BEE
3 - 17 - 64

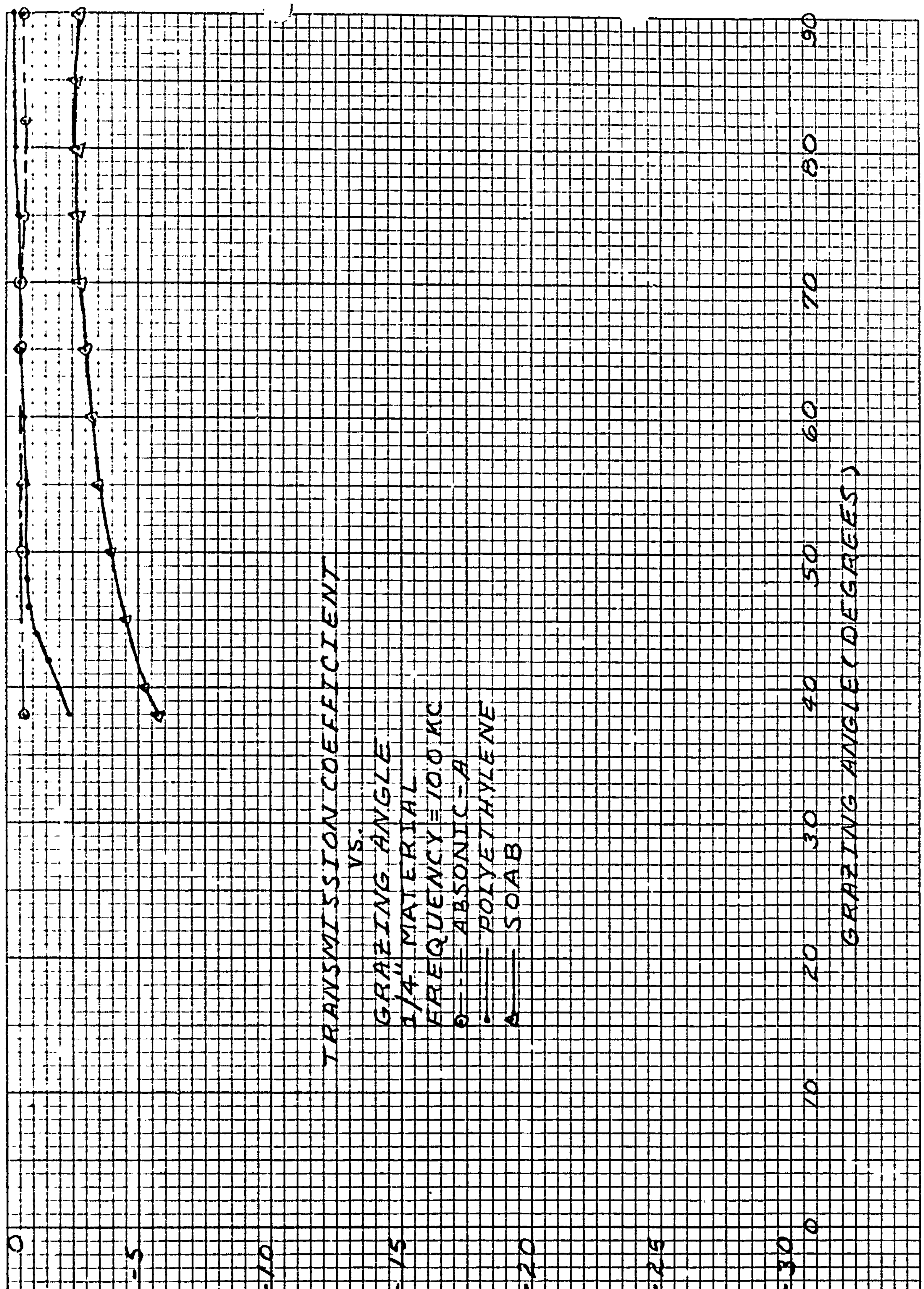

REFLECTION COEFFICIENT
VS.
GRAZING ANGLE
1/4" ABSONIC-A
FREQUENCY = 500KC
AZ = 70 DB/FT
AZT = 140 DB/FT
MEASURED
CALCULATED
GRAZING ANGLE (DEGREES)
20 LOG$_{10}$ |V| (DB)
0
-5
-10
-15
-20
-25
-30
0
10
20
30
40
50
60
70
80
90

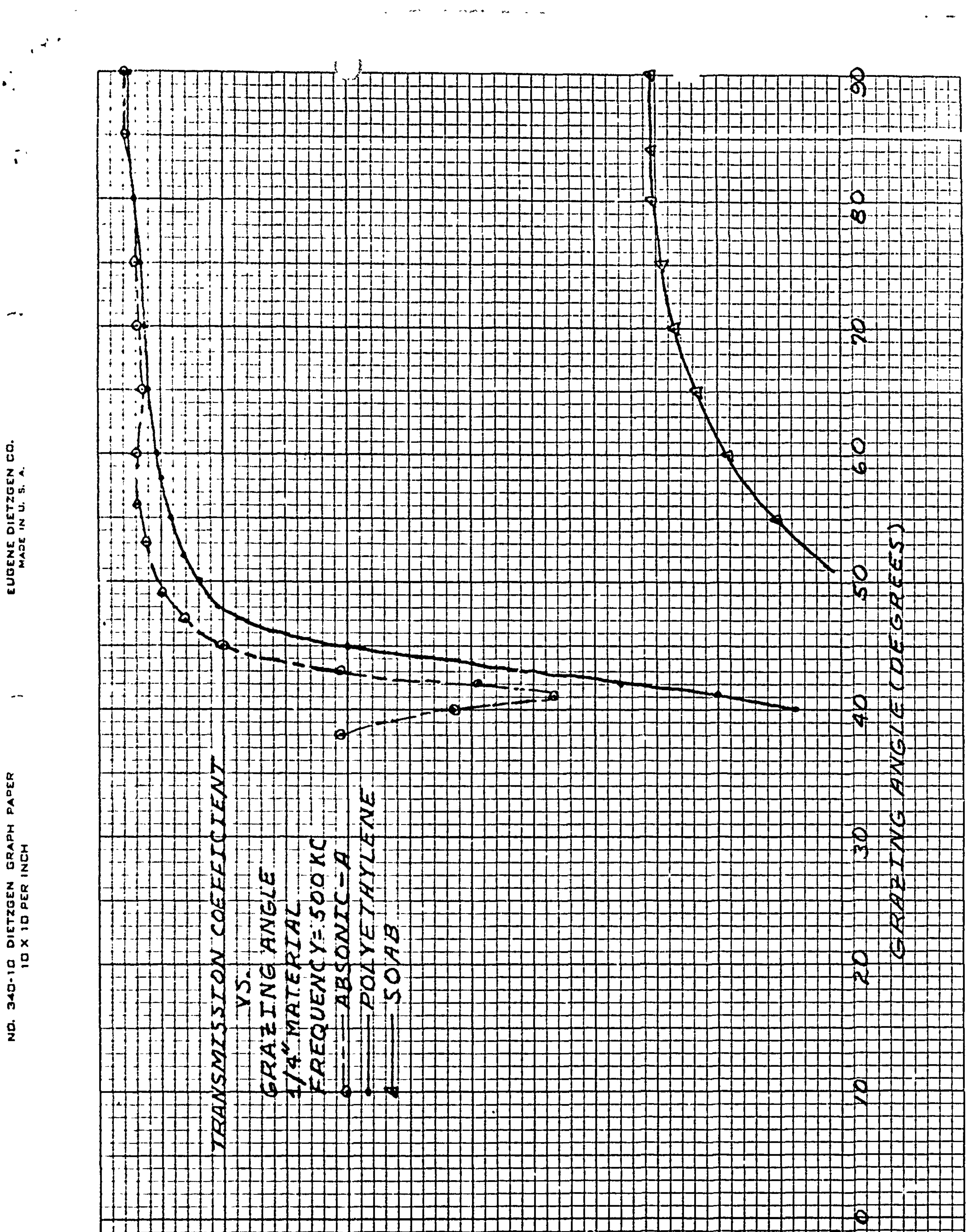
Slide 5


TRANSMISSION COEFFICIENT
VS.
GRAZING ANGLE
1/4" ABSONIC-A
FREQUENCY=500 KC
A2=70 DB/FT
A2T=140 DB/FT
MEASURED
CALCULATED
20 LOG10 |T| (DB)
0
-5
-10
-15
-20
-25
-30
0
10
20
30
40
50
60
70
80
90
GRAZING ANGLE (DEGREES)

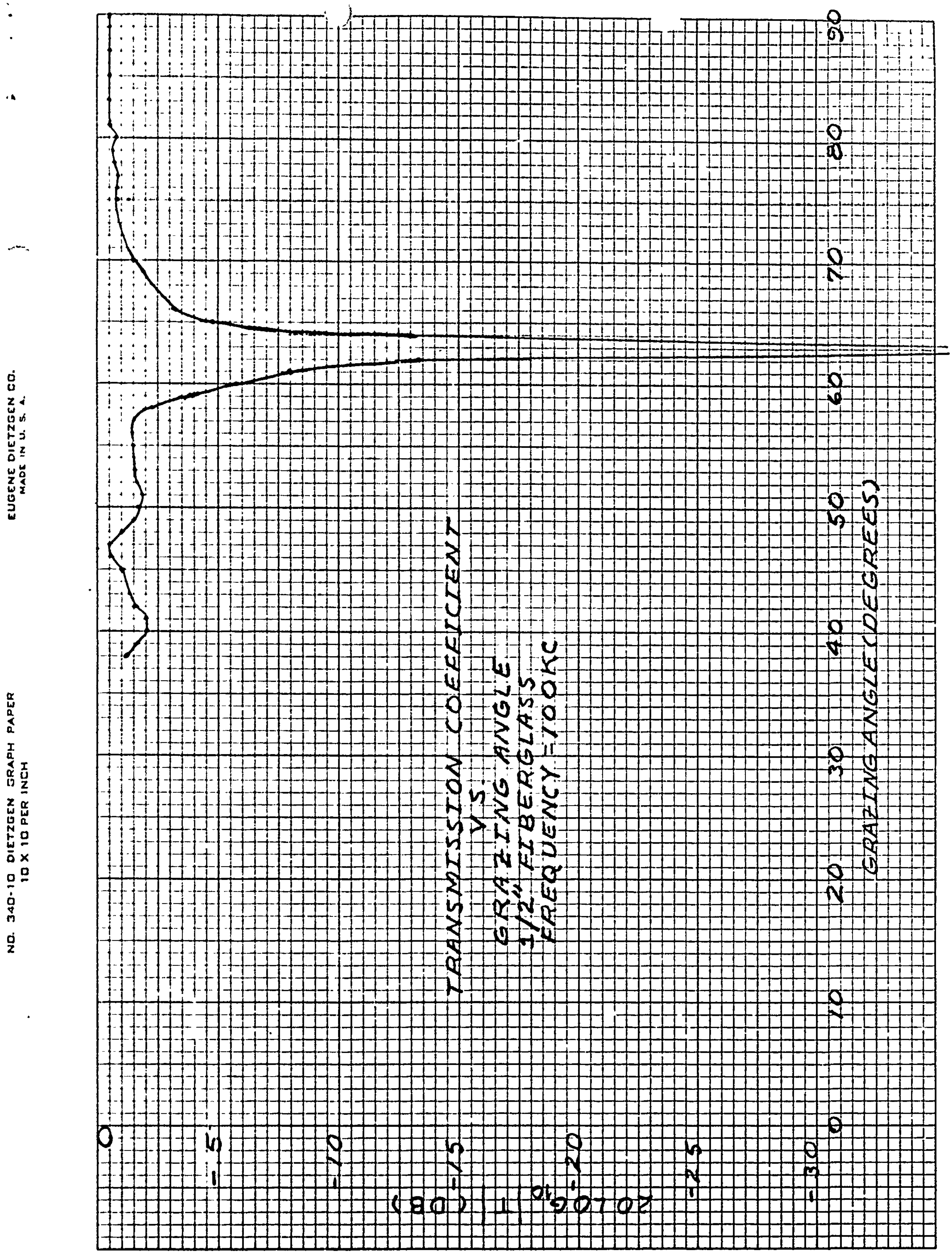

TRANSMISSION COEFFICIENT
VS.
GRAZING ANGLE
1/4" MATERIAL
FREQUENCY = 270 KC
ABSONIC-A
PLEXIGLAS
GRAZING ANGLE (DEGREES)
0
10
20
30
40
50
60
70
80
90
20 LOG10 |T| (DB)
0
-5
-10
-15
-20
-25
-30

Slide 7


TRANSMISSION COEFFICIENT
VS.
GRAZING ANGLE
1/4" MATERIAL
FREQUENCY = 100 KC
ABSONIC-A
POLYETHYLENE
SOAB
GRAZING ANGLE (DEGREES)
$20 \log_{10} |T|$ (DB)
0
10
20
30
40
50
60
70
80
90
0
-5
-10
-15
-20
-25
-30


NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.
TRANSMISSION COEFFICIENT
VS.
GRAZING ANGLE
1/4" MATERIAL
FREQUENCY = 500 KC
ABSONIC-A
POLYETHYLENE
SOAB
0
10
20
30
40
50
60
70
80
90
GRAZING ANGLE (DEGREES)
0
-5
-10
-15
-20
-25
-30
20 LOG10 |T| (DB)

Slide 9


TRANSMISSION COEFFICIENT
VS.
GRAZING ANGLE
1/2" FIBERGLASS
FREQUENCY=100KC
GRAZING ANGLE (DEGREES)
20 LOG10 |T| (DB)
0
-5
-10
-15
-20
-25
-30
0
10
20
30
40
50
60
70
80
90
NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.